

(12) **United States Patent**  
**Ueda et al.**

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(54) **METHOD FOR MANUFACTURING  
ACOUSTIC WAVE DEVICE**

H03H 9/0504; Y10T 29/42; Y10T 29/49005;  
Y10T 29/49155; H01L 41/312; H01L 41/337  
See application file for complete search history.

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(\*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 809 days.

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(21) Appl. No.: **13/362,743**

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(65) **Prior Publication Data**

US 2012/0198672 A1 Aug. 9, 2012

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(30) **Foreign Application Priority Data**

Feb. 4, 2011 (JP) ..... 2011-023073

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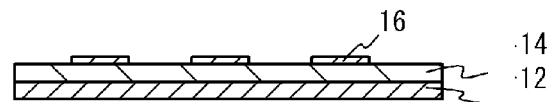
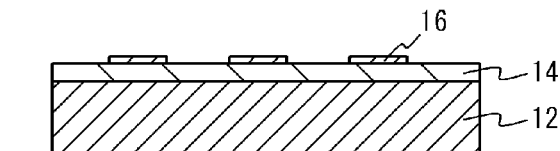
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(57) **ABSTRACT**

A method for manufacturing an acoustic wave device includes: bonding a piezoelectric substrate to a first surface of a first support substrate; thinning the piezoelectric substrate after the bonding to thus form a piezoelectric layer; forming a first electrode on a first surface of the piezoelectric layer; forming holes in the first support substrate located below the first electrode; and bonding a second support substrate to a second surface of the first support substrate opposite to the first surface after the forming of holes.

**12 Claims, 17 Drawing Sheets**



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FIG. 1A

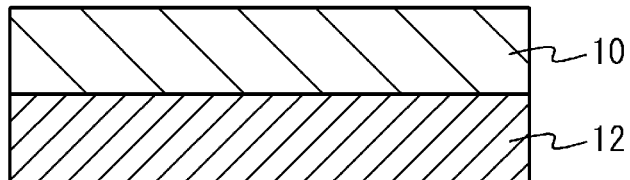


FIG. 1B

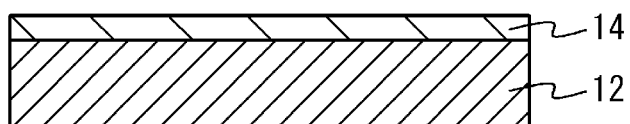


FIG. 1C

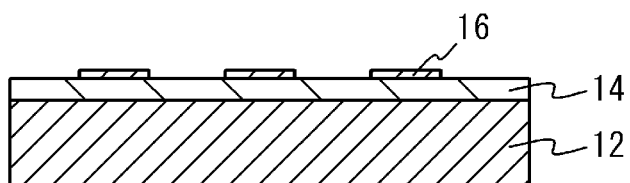


FIG. 1D

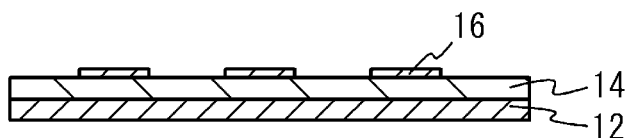


FIG. 1E

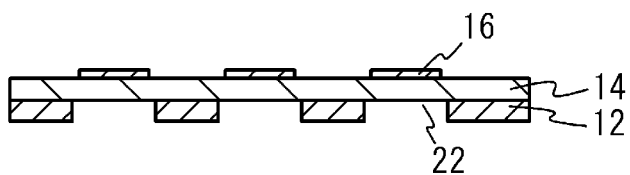


FIG. 1F

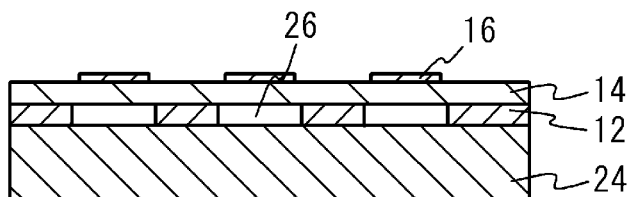


FIG. 2A

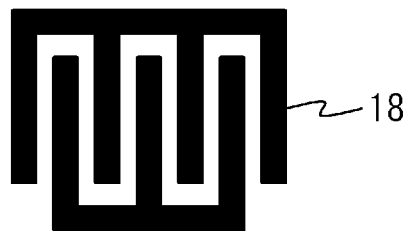


FIG. 2B

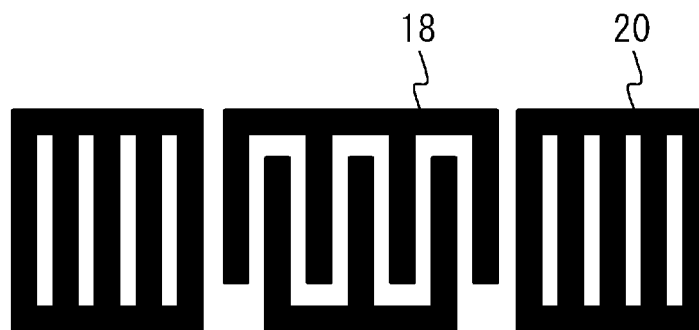


FIG. 3A

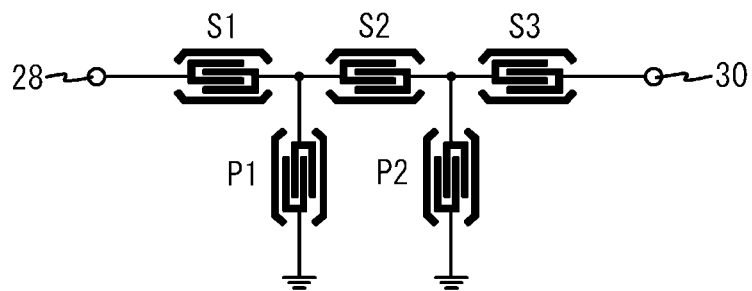


FIG. 3B

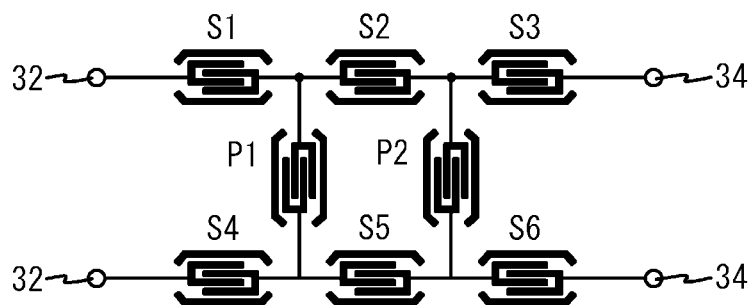


FIG. 3C

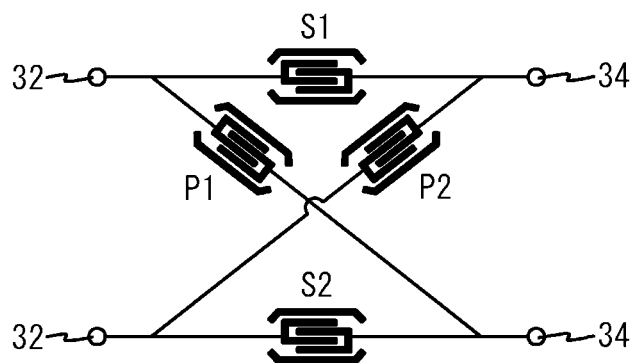


FIG. 3D

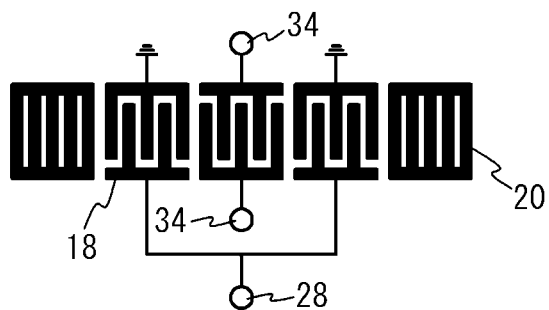


FIG. 4A

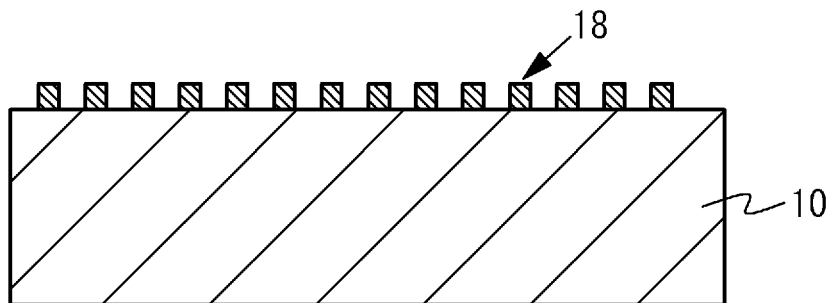


FIG. 4B

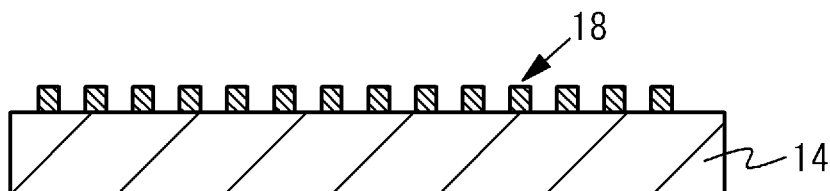


FIG. 5

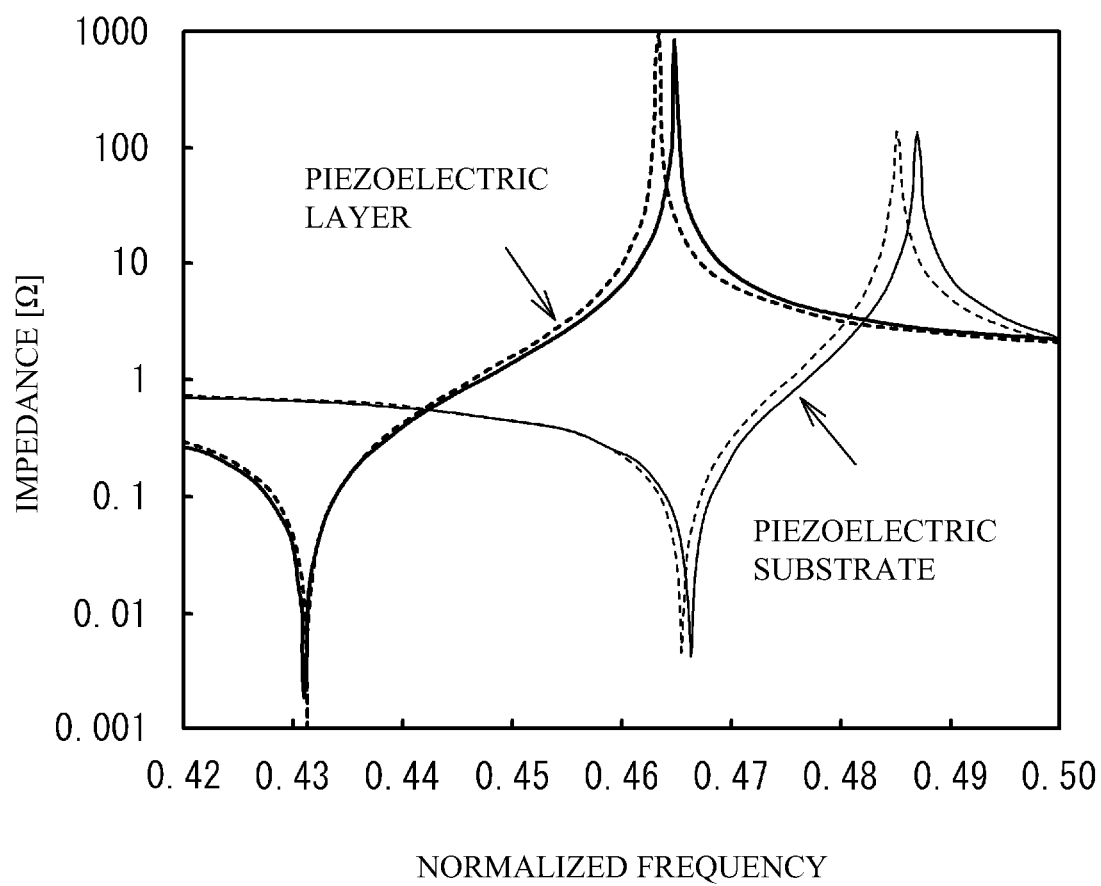


FIG. 6A

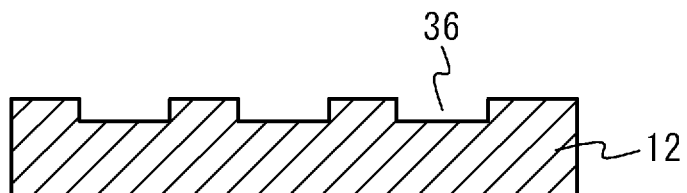


FIG. 6B

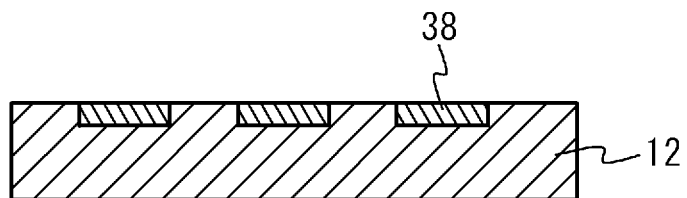


FIG. 6C

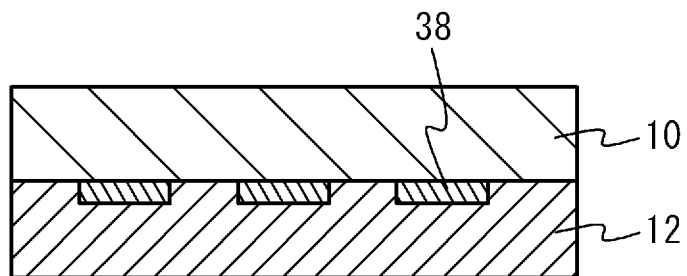


FIG. 6D

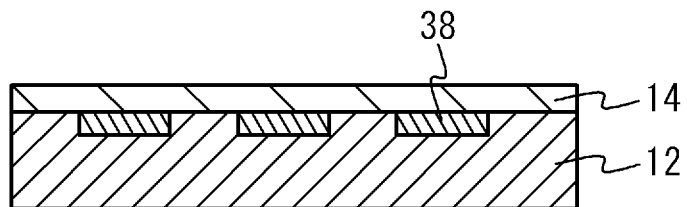




FIG. 7A

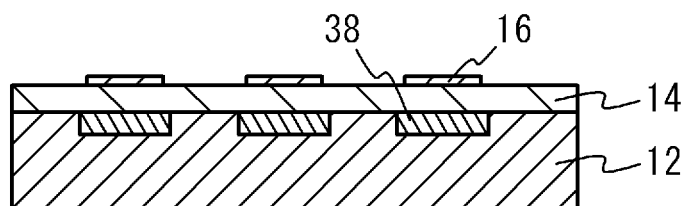


FIG. 7B

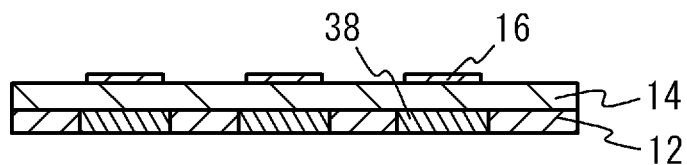


FIG. 7C

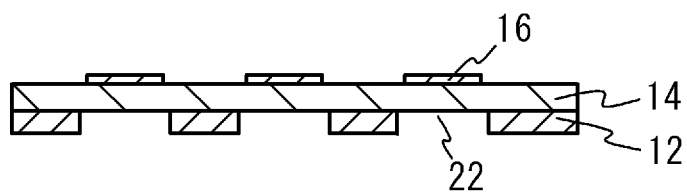


FIG. 7D

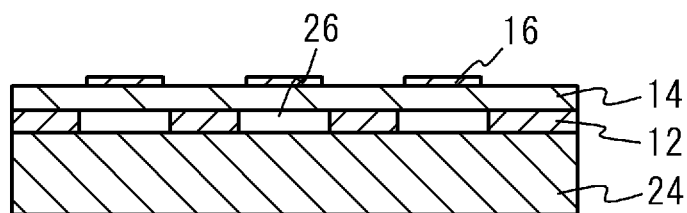


FIG. 8A

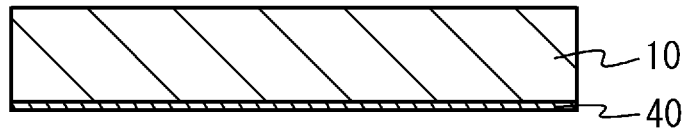


FIG. 8B

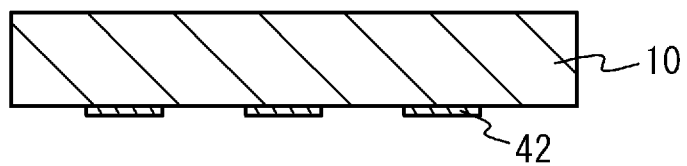


FIG. 8C

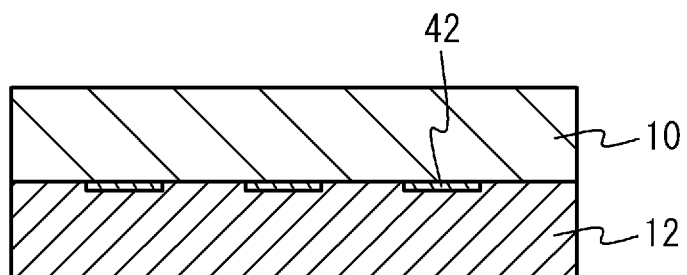


FIG. 8D

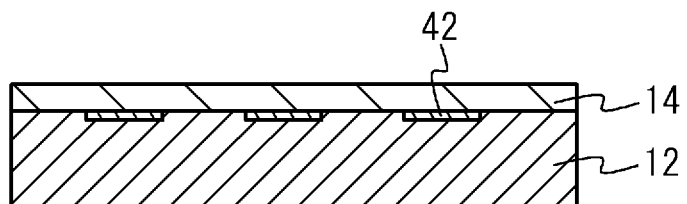


FIG. 9A

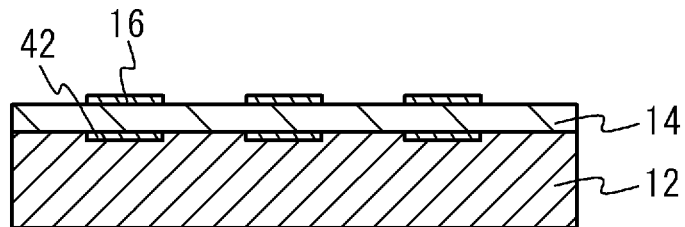


FIG. 9B

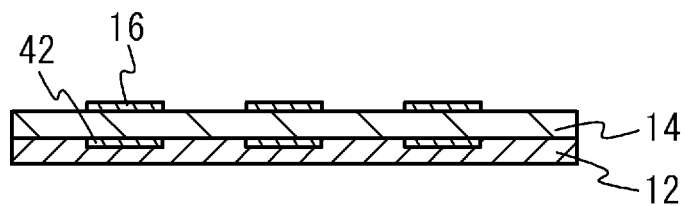


FIG. 9C

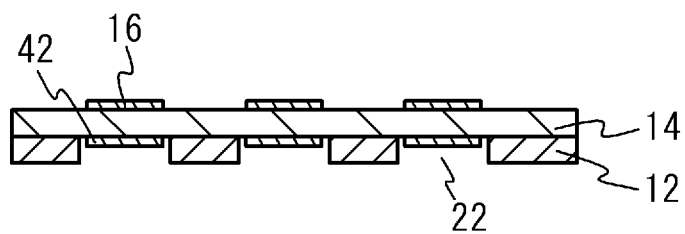


FIG. 9D

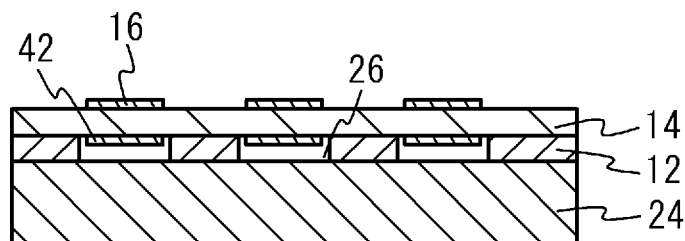


FIG. 10A

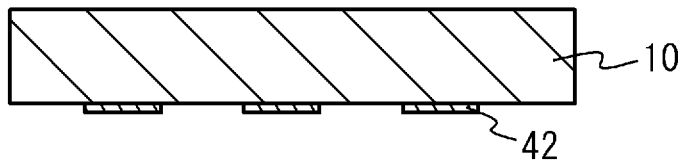


FIG. 10B

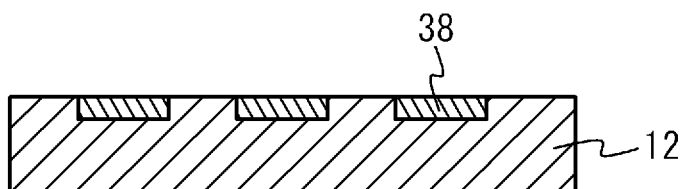


FIG. 10C

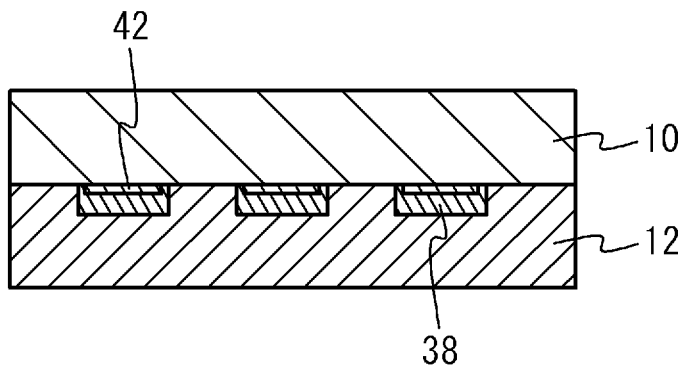


FIG. 10D

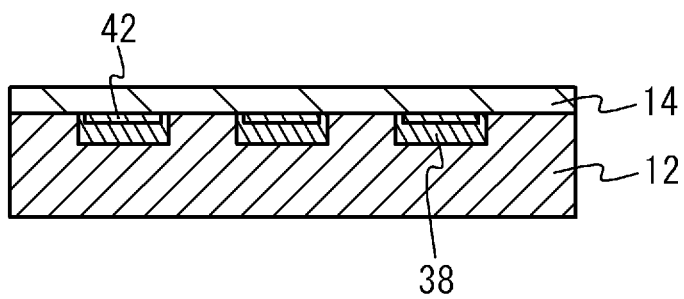


FIG. 11A

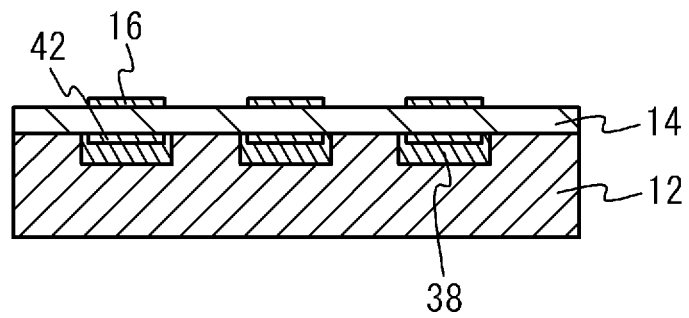


FIG. 11B

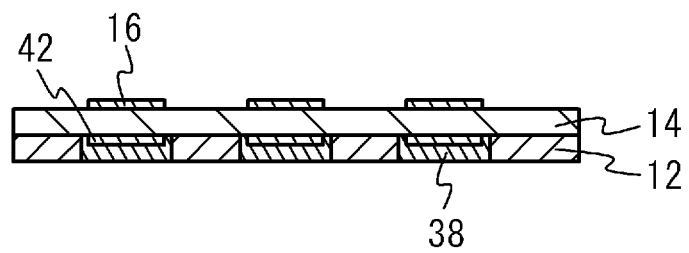


FIG. 11C

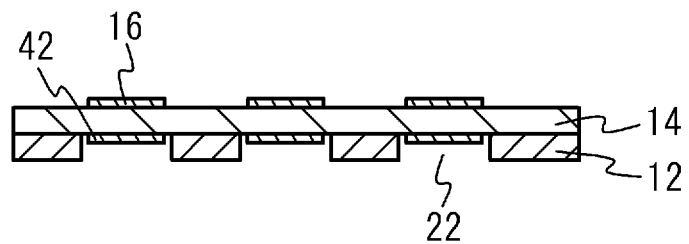


FIG. 11D

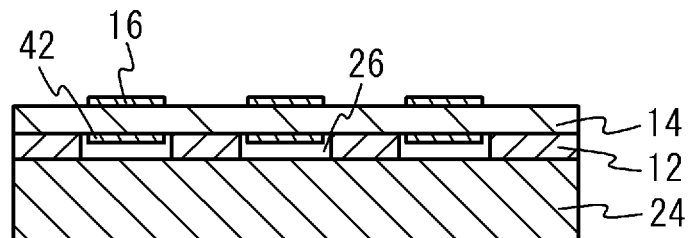


FIG. 12A

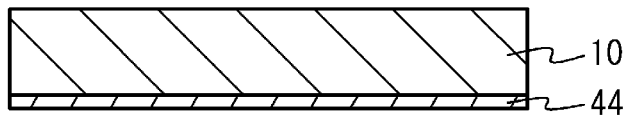


FIG. 12B

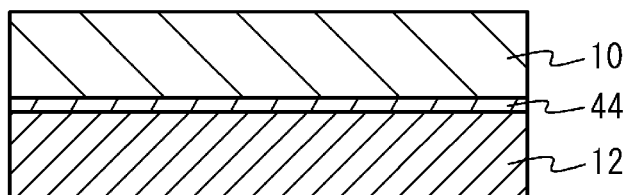


FIG. 12C

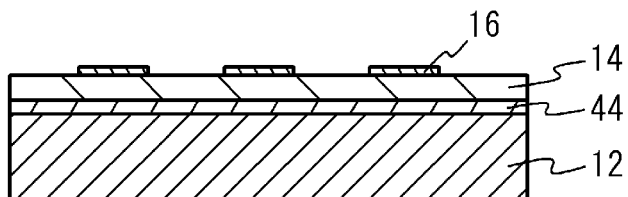


FIG. 12D

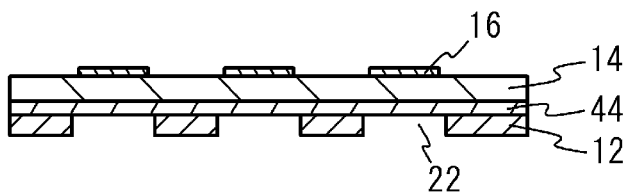


FIG. 12E

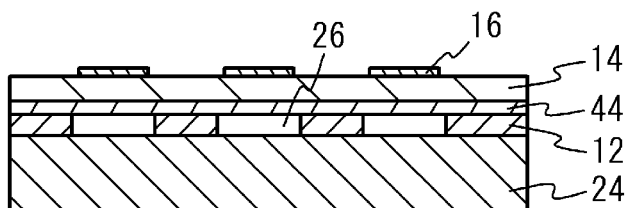


FIG. 13A

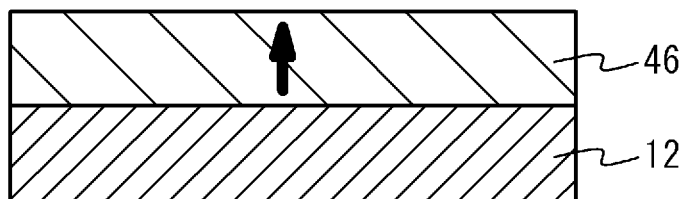


FIG. 13B

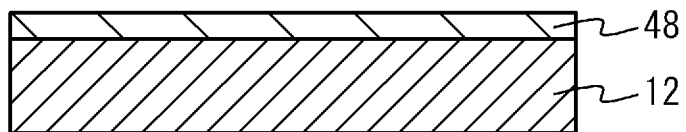


FIG. 13C

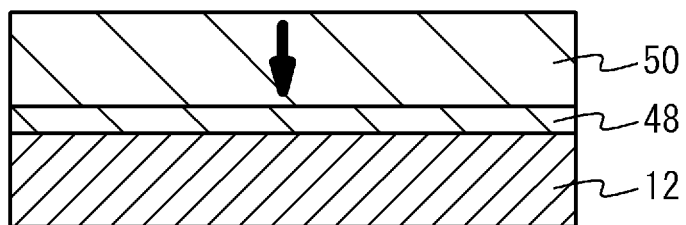


FIG. 13D

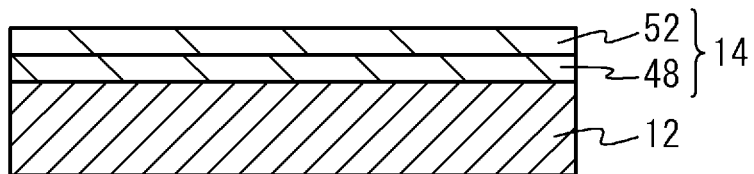


FIG. 14A

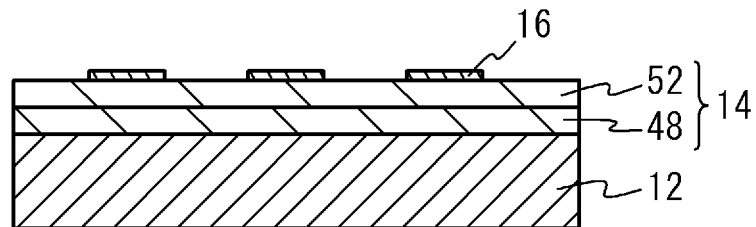


FIG. 14B

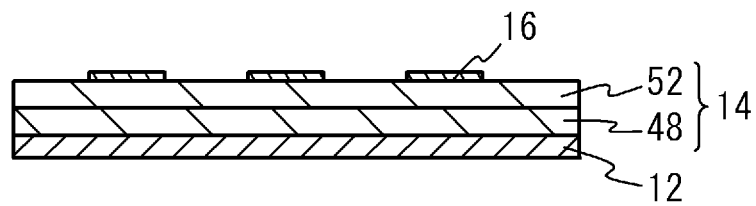


FIG. 14C

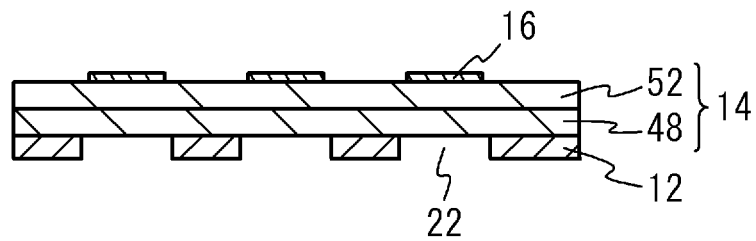


FIG. 14D

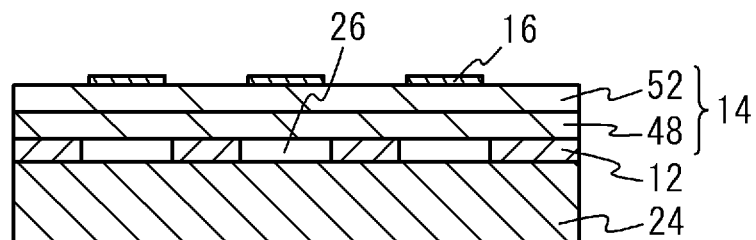




FIG. 15

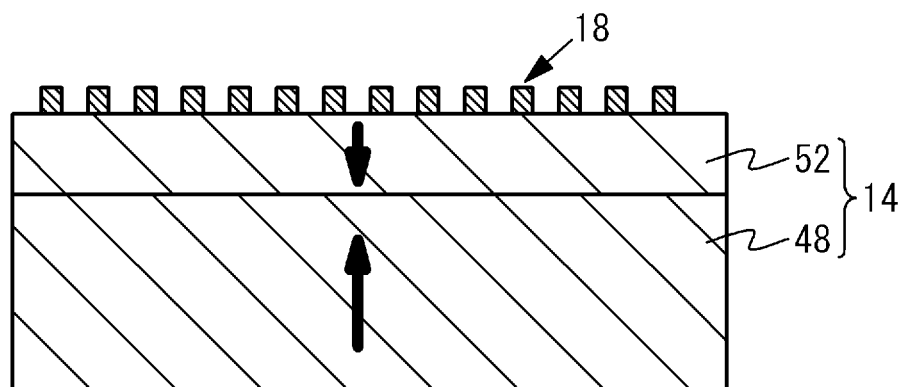


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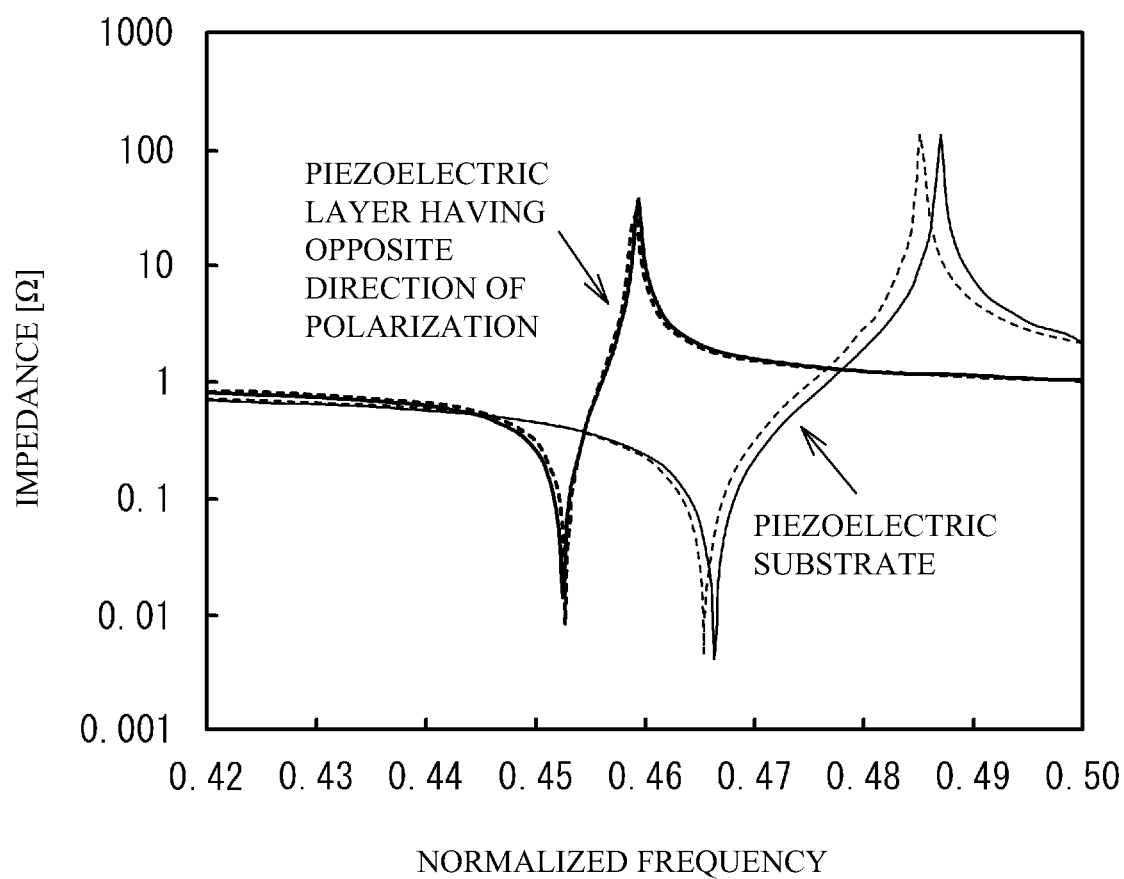


FIG. 17A

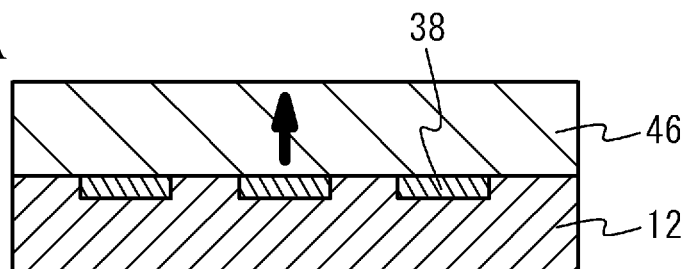


FIG. 17B

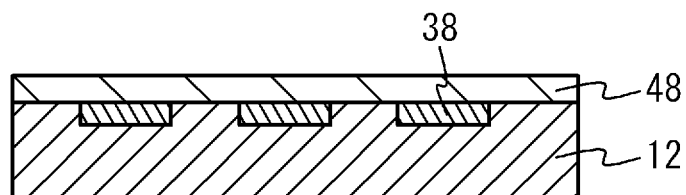


FIG. 17C

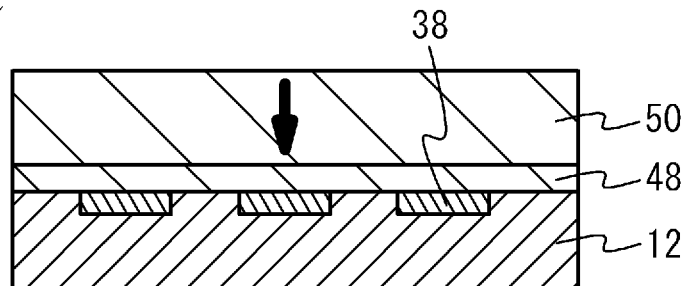
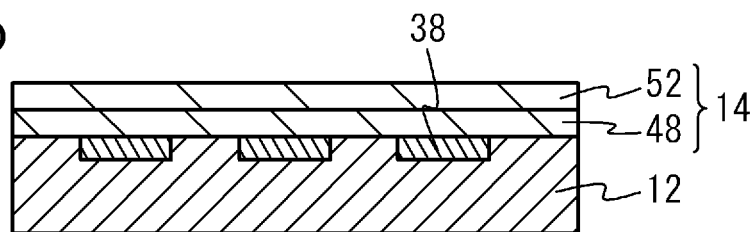


FIG. 17D



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# METHOD FOR MANUFACTURING ACOUSTIC WAVE DEVICE

## CROSS-REFERENCE TO RELATED APPLICATION

This application is based upon and claims the benefit of priority of the prior Japanese Patent Application No. 2011-023073, filed on Feb. 4, 2011, the entire contents of which are incorporated herein by reference.

## FIELD

A certain aspect of the present invention relates to a method for manufacturing an acoustic wave device. Another aspect of the present invention relates to a method for manufacturing an acoustic wave device utilizing a thin piezoelectric layer.

## BACKGROUND

There is known a surface acoustic wave (SAW) device as an acoustic wave device using an acoustic wave. The SAW device is compact and light and is capable of attenuating signals greatly. Therefore, the SAW device is used as a filter for mobile communications such as portable phones.

Recently, a Lamb wave device and a film bulk acoustic resonator (FBAR) that use a thin piezoelectric layer have been proposed as devices obtained by developing the SAW device (see Japanese Patent Application Publication No. 2010-136317: Document 1). An acoustic wave device using a thin piezoelectric layer may have a structure in which a support substrate having a recess portion is bonded to a piezoelectric layer, and an electrode is provided to an upper surface of the piezoelectric layer or both the upper and lower surfaces thereof above a hollow portion defined by the recess portion.

There are various proposed methods for manufacturing the acoustic wave device utilizing the thin piezoelectric layer. For example, Document 1 discloses that the recess portion is formed in an area of the support substrate that is to be formed into the hollow portion, and is filled with a sacrificing layer beforehand. A piezoelectric substrate is bonded to the support substrate, and is then thinned to form the piezoelectric layer. Then, the electrode is formed on the upper surface of the piezoelectric layer. Finally, the sacrificing layer is removed through a via hole that is formed beforehand, whereby the hollow portion can be defined.

The method proposed in Document 1 is capable of preventing an unevenness of the thickness of the piezoelectric layer, as compared with a comparative case where the piezoelectric substrate is bonded to the support substrate having the recess portion that is not filled with the sacrificing layer (see paragraph 0142 and FIG. 36 of Document 1). However, there is a room left for improvement in the manufacturing method when aspects of productivity and easy manufacturability are taken into consideration.

## SUMMARY OF THE INVENTION

According to an aspect of the present invention, there is provided a method for easily manufacturing an acoustic wave device with an improved productivity.

According to another aspect of the present invention, there is provided a method for manufacturing an acoustic wave device including: bonding a piezoelectric substrate to a first surface of a first support substrate; thinning the piezoelectric substrate after the bonding to thus form a piezoelectric layer; forming a first electrode on a first surface of the piezoelectric

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layer; forming holes in the first support substrate located below the first electrode; and bonding a second support substrate to a second surface of the first support substrate opposite to the first surface after the forming of holes.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. 1A through 1F are cross-sectional views that illustrate a series of steps of a first method for manufacturing an acoustic wave device in accordance with a first embodiment;

FIGS. 2A and 2B are schematic views of a first electrode;

FIGS. 3A through 3D are schematic views of cases where an acoustic wave device of the first embodiment is used as a filter;

FIGS. 4A and 4B are cross-sectional views of a structure used in a simulation;

FIG. 5 illustrates results of the simulation;

FIGS. 6A through 6D are cross-sectional views of a series of steps of a second method for manufacturing an acoustic wave device in accordance with the first embodiment;

FIGS. 7A through 7D are cross-sectional views of a series of steps of the second method that follows the series of steps in FIGS. 6A through 6D;

FIGS. 8A through 8D are cross-sectional views of a series of steps of a first method for manufacturing an acoustic wave device in accordance with a second embodiment;

FIGS. 9A through 9D are cross-sectional views of a series of steps that follows the series of steps in FIGS. 8A through 8D;

FIGS. 10A through 10D are cross-sectional views of a series of steps of a second method for manufacturing an acoustic wave device in accordance with the second embodiment;

FIGS. 11A through 11D are cross-sectional views of a series of steps that follows the series of steps in FIGS. 10A through 10D;

FIGS. 12A through 12E are cross-sectional views of a series of steps of a method for manufacturing an acoustic wave device in accordance with a third embodiment;

FIGS. 13A through 13D are cross-sectional views of a series of steps of a method for manufacturing an acoustic wave device in accordance with a fourth embodiment;

FIGS. 14A through 14D are cross-sectional views of a series of steps that follows the series of steps in FIGS. 13A through 13D;

FIG. 15 is a cross-sectional view of a structure used in a simulation;

FIG. 16 illustrates results of the simulation; and

FIGS. 17A through 17D are cross-sectional views of a series of steps of a second method for manufacturing an acoustic wave device in accordance with the fourth embodiment.

## DETAILED DESCRIPTION

Exemplary embodiments of the invention are described with reference to the accompanying drawings.

### First Embodiment

An acoustic wave device in accordance with a first embodiment is a SAW device. A description is now given of a first method for manufacturing an acoustic wave device in accordance with the first embodiment with reference to FIGS. 1A through 1F. Referring to FIG. 1A, a lower surface of a piezoelectric substrate 10 is bonded to an upper surface of a first support substrate 12. The piezoelectric substrate 10 may be a

lithium tantalate ( $\text{LiTaO}_3$ ) substrate or a lithium niobate ( $\text{LiNbO}_3$ ) substrate, which are respectively referred to as LT substrate and LN substrate in the following description. The first support substrate **12** may be a silicon (Si) substrate, for example. The method of bonding the piezoelectric substrate **10** and the first support substrate **12** may be a surface activation bonding method or a resin bonding method.

Referring to FIG. 1B, the piezoelectric substrate **10** is thinned under the condition that the piezoelectric substrate **10** has been bonded to the first support substrate **12**. The piezoelectric substrate **10** is thinned to define a piezoelectric layer **14** having a thickness of, for example, 5  $\mu\text{m}$ . The thinning method may be mechanical processing such as grinding or polishing.

Referring to FIG. 1C, a first electrode **16** is formed on the upper surface of the piezoelectric layer **14**. The first electrode **16** may be formed as follows. A metal film made of aluminum (Al) or copper (Cu) is formed on the whole upper surface of the piezoelectric layer **14** by a sputtering or evaporation technique so as to have a thickness of, for example, 0.1  $\mu\text{m}$ –0.5  $\mu\text{m}$ . Then, unnecessary portions of the metal film are removed by etching. FIGS. 2A and 2B illustrate examples of the first electrode **16**. The first electrode **16** illustrated in FIG. 2A is a pair **18** of comb-tooth electrodes (interdigital electrode). The first electrode **16** illustrated in FIG. 2B includes reflection electrodes **20** arranged at both sides of the pair **18** of comb-tooth electrodes in the acoustic wave propagation direction.

Referring to FIG. 1D, the first support substrate **12** is thinned so as to have a thickness of 50  $\mu\text{m}$ , for example. The method for thinning the first support substrate **12** may be mechanical processing such as grinding or polishing as in the case of thinning the piezoelectric substrate **10** in FIG. 1B.

As illustrated in FIG. 1E, portions of the first support substrate **12** that are located in areas below the first electrode **16** are removed so as to form holes **22**. The area in which the holes **22** are formed is designed to be larger than that in which the first electrode **16** is formed. That is, in the area in which the first electrode **16** is formed, the holes **22** are formed below the piezoelectric layer **14**. The holes **22** may be formed by dry etching or wet etching.

Referring to FIG. 1F, the second support substrate **24** is bonded to the lower surface of the first support substrate **12**. By this bonding, the holes **22** are formed into the hollow portions **26**, and the first electrode **16** is provided on the upper surface of the piezoelectric layer **14** above the hollow portions **26**. The area of the piezoelectric layer **14** in which the first electrode **16** is provided is an exciting portion. The exciting portion of the piezoelectric layer **14** is separated from the first support substrate **12**. The second support substrate **24** may be a silicon substrate, for example. The method for bonding the first support substrate **12** and the second support substrate **24** to each other may be a surface activation bonding method or a resin bonding method as in the case of bonding the piezoelectric substrate **10** and the first support substrate **12** to each other.

FIGS. 3A through 3D are schematic views of filters using the acoustic wave device of the first embodiment. A plurality of pairs **18** of comb-tooth electrodes each illustrated in FIGS. 2A and 2B function as resonators and may be combined so as to form a filter. FIGS. 3A and 3B illustrate ladder filters. More specifically, FIG. 3A illustrates a single-end type ladder filter, and FIG. 3B illustrates a balanced type ladder filter. FIG. 3C illustrates a balanced type lattice filter, and FIG. 3D illustrates a double-mode type SAW filter.

Referring to FIG. 3A, the single-end type ladder filter is composed of series resonators **S1** through **S3** connected in series with each other between a single unbalanced input

terminal **28** and a single unbalanced output terminal **30**, and parallel resonators **P1** and **P2** connected in parallel with the series resonators **S1** through **S3**. Referring to FIG. 3B, the balanced type ladder filter is composed of series resonators **S1** through **S3** connected in series with one of the two balanced input terminals **32** and one of the two balanced output terminals **34**, series resonators **S4** through **S6** connected in series with the other input terminal **32** and the other output terminal **34**, and parallel resonators **P1** and **P2** connected in parallel with the series resonators **S1** through **S6**.

Referring to FIG. 3C, the balanced type lattice filter includes two series resonators **S1** and **S2** that are connected in series with the two input terminals **32** and the two output terminals **34** as illustrated. The parallel resonator **P1** is connected between the input terminal **32** connected to the series resonator **S1** and the output terminal **34** connected to the series resonator **S2**. The parallel resonator **P2** is connected between the input terminal **32** connected to the series resonator **S2** and the output terminal **34** connected to the series resonator **S1**. As illustrated in FIG. 3D, the double-mode type SAW filter has three pairs **18** of comb-tooth electrodes arranged side by side in the SAW propagation direction, and two reflection electrodes **20** are provided further out than the arrangement of the three pairs **18**. The unbalanced input terminal **28** is connected to one of the pair **18** of comb-tooth electrodes located on the left side of the arrangement and is connected to one of the pair **18** of comb-tooth electrodes located on the right side thereof. Two balanced output terminals **34** are connected to the pair **18** of comb-tooth electrodes located in the center of the arrangement.

The inventors conducted a simulation in order to study that thinning of the piezoelectric substrate **10** to form the piezoelectric layer **14** brings about an improvement in the impedance characteristic. FIGS. 4A and 4B are schematic cross-sectional views of structures used in the simulation. FIG. 4A illustrates a simulation structure having the piezoelectric substrate **10** that is a general piezoelectric substrate and is relatively thick. FIG. 4B illustrates another simulation structure using the piezoelectric layer **14** formed by thinning the piezoelectric substrate **10**. The structure illustrated in FIG. 4A is as follows. The piezoelectric substrate **10** is formed by 42°-rotated Y-cut LT, and has a thickness of  $100\lambda$  where  $\lambda$  is the wavelength of the acoustic wave propagated on the piezoelectric substrate. One pair **18** of comb-tooth electrodes that is made of aluminum and has the infinite period is formed on the upper surface of the piezoelectric substrate **10**. The structure illustrated in FIG. 4B is as follows. The piezoelectric layer **14** is formed by 42°-rotated Y-cut LT, and has a thickness of  $0.2\lambda$ . One pair **18** of comb-tooth electrodes that is made of aluminum and has the infinite period is formed on the upper surface of the piezoelectric layer **14**.

FIG. 5 illustrates results of the simulation. The horizontal axis of FIG. 5 is the normalized frequency described as  $f(p/V_b)$  where  $f$  is the frequency,  $p$  is the electrode pitch, and  $V_b$  is the acoustic velocity of the bulk wave (for example, 42°-rotated Y-cut LT has an acoustic velocity of 4226 m/s). The vertical axis of FIG. 5 is the impedance ( $\Omega$ ). Solid lines in FIG. 5 are impedance characteristics obtained at room temperature (25° C.), and broken lines are impedance characteristics at a high temperature (125° C.). As illustrated in FIG. 5, the structure using the piezoelectric substrate **10** (thin lines in FIG. 5) has an electromechanical coupling coefficient  $K^2$  of 10%, a temperature coefficient of velocity (TCV) of  $-18.4 \text{ ppm}/^\circ\text{C}$ . at the resonance frequency, and a TCV of  $-29.6 \text{ ppm}/^\circ\text{C}$ . at the anti-resonance frequency. The structure using the piezoelectric substrate **14** (thick lines in FIG. 5) has an  $K^2$

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of 16.6%, a TCV of +6.1 ppm/ $^{\circ}$  C. at the resonance frequency, and a TCV of -14.5 ppm/ $^{\circ}$  C. at the anti-resonance frequency.

As described above, the use of the piezoelectric layer **14** brings about an increased K2 and TCVs close to zero at the resonance and anti-resonance frequencies. That is, the use of the piezoelectric layer **14** improves K2 and TCV of the device characteristics.

As described above, according to the first method for manufacturing the acoustic wave device in accordance with the first embodiment, the piezoelectric substrate **10** is bonded to the upper surface of the first support substrate **12** in which the recess portions are not formed, and is then thinned to form the piezoelectric layer **14**. That is, in the state in which the whole surface of the piezoelectric substrate **10** is bonded to the first support substrate **12**, the piezoelectric substrate **10** is thinned to form the piezoelectric layer **14**. It is thus possible to prevent the film thickness of the piezoelectric layer **14** from being made uneven.

As illustrated in FIGS. **1E** and **1F**, the holes **22** are formed by removing the portions of the first support substrate **12** located below the first electrode **16**, and the second support substrate **24** is bonded to the lower surface of the first support substrate **12**. The portion of the piezoelectric layer **14** on which the first electrode **16** is formed is the exciting portion, which is separated from the first support substrate **12**, whereby the SAW device having an improved excitation efficiency is realized.

In the manufacturing method described in Document 1, the sacrificing layer is buried in the recess portion located in the area that is to be the hollow portion, and the via hole for removal of the sacrificing layer is formed in the piezoelectric substrate or the support substrate. In contrast, the first manufacturing method of the first embodiment does not use the sacrificing layer and does not need the via hole.

According to the first method for manufacturing the acoustic wave of the first embodiment, it is possible to easily manufacture the SAW device that has the piezoelectric layer **14** having uniform thickness and has the exciting portion of the piezoelectric layer **14** separated from the first support substrate **12**. It is possible to easily manufacture the SAW device having excellent device characteristics such as K2 and TCV as illustrated in FIG. **5** with excellent productivity.

Further, as illustrated in FIGS. **1D** and **1E**, it is preferable that the first support substrate **12** is thinned, and the holes **22** are then formed by removing the portions of the first piezoelectric substrate **12** located below the first electrode **16**. This sequence makes it possible to use a reduced amount of etching for forming the holes **22**. Thus, the controllability of forming the holes **22** (that is, the hollow portions **26**) can be improved and the hollow portions **26** can be formed easily.

The structure used in the simulation illustrated in FIG. **4B** employs 42 $^{\circ}$ -rotated Y-cut LT for the piezoelectric layer **14** and an ability of efficiently exciting a shear horizontal (SH) wave, whereby excellent device characteristics are obtained. Similar excellent device characteristics may be obtained when 64 $^{\circ}$ -rotated Y-cut LN is used. Thinning of LT or LN makes it possible to confine the acoustic wave within the piezoelectric substrate and to prevent the occurrence of bulk wave emission loss inherent in the leakage acoustic wave. The acoustic wave device thus manufactured has low loss and a high Q value. From the above viewpoints, the piezoelectric layer **14** is preferably made of LT or LN.

The first support substrate **12** and the second support substrate **24** are not limited to the silicon substrates but may be made of another substance. Preferably, a substance has a property of making it possible to easily form the holes **22** and

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perform bonding to the piezoelectric substrate **10**. For example, a substrate having a main component of Si such as a SiO<sub>2</sub> substrate may be used.

A description is now given of a second method for manufacturing an acoustic wave device in accordance with the second embodiment with reference to FIGS. **6A** through **7D**. Referring to FIG. **6A**, recess portions **36** that have a depth of 10  $\mu$ m, for example, are formed in the upper surface of the first support substrate **12** by etching. This etching may be dry etching or wet etching.

Referring to FIG. **6B**, a sacrificing layer **38**, which may be an oxide film such as a silicon oxide film, is deposited to the whole upper surface of the first support substrate **12** so as to be buried in the recess portions **36**. Thereafter, the sacrificing layer **38** is grinded until the upper surface of the first support substrate **12** is exposed. Thus, the first support substrate **12** in which only the recess portions **36** are full of the sacrificing layer **38** is obtained. The sacrificing layer **38** is not limited to the silicon oxide film but may be made of a material that does not remove or damage the first support substrate **12**, the piezoelectric layer **14** and the first electrode **16** at the time of removing the sacrificing layer **38**.

Referring to FIG. **6C**, the piezoelectric substrate **10** is bonded to the upper surface of the first support substrate **12** on which the sacrificing layer **38** is formed. Referring to FIG. **6D**, the piezoelectric substrate **10** is thinned to thus form the piezoelectric layer **14** in the state in which the piezoelectric substrate **10** has been bonded to the first support substrate **12**.

Referring to FIG. **7A**, the first electrode **16** is formed on the piezoelectric substrate **14** above the area in which the sacrificing layer **38** is formed. The first electrode **16** and the sacrificing layer **38** face each other through the piezoelectric layer **14**. The recess portions **36** are formed so that the area in which the sacrificing layer **38** is provided is larger than the area in which the first electrode **16** is formed.

Referring to FIG. **7B**, the first support substrate **12** is thinned until the sacrificing layer **38** is exposed. Referring to FIG. **7C**, the exposed sacrificing layer **38** is removed by etching, whereby the holes **22** are formed in the area of the first support substrate **12** located below the first electrode **16**, the above area being larger than the area in which the first electrode **16** is formed. The above etching may be dry etching or wet etching.

Referring to FIG. **7D**, the second support substrate **24** is bonded to the lower surface of the first support substrate **12**. Thus, the holes **22** are formed into the hollow portions **26**, and the first electrode **16** is provided on the upper surface of the piezoelectric layer **14** located above the hollow portions **26**.

As described above, according to the second method for manufacturing the acoustic wave device in accordance with the first embodiment, as illustrated in FIGS. **6A** and **6B**, the recess portions **36** are formed in the upper surface of the first support substrate **12**, and are filled with the sacrificing layer **38**. Next, as illustrated in FIG. **6C**, the piezoelectric substrate **10** is bonded to the upper surface of the first support substrate **12** on which the sacrificing layer **38** is formed. Then, as illustrated in FIG. **6D**, the piezoelectric substrate **10** is thinned to form the piezoelectric layer **14**. That is, the piezoelectric substrate **10** is thinned to form the piezoelectric layer **14** in the state in which the whole surface of the piezoelectric substrate **10** is bonded to the first support substrate **12** and the sacrificing layer **38**. It is thus possible to prevent the film thickness of the piezoelectric layer **14** from being made uneven.

As illustrated in FIG. **7B**, the first support substrate **12** is thinned until the sacrificing layer **38** is exposed. As illustrated in FIG. **7C**, the exposed sacrificing layer **38** is removed to

form the holes 22 below the first electrode 16 by removing the exposed sacrificing layer 38. Thereafter, as illustrated in FIG. 7D, the second support substrate 24 is bonded to the lower surface of the first support substrate 12. It is thus possible to remove the sacrificing layer 38 without the via hole for removal of the sacrificing layer 38 that is employed in the manufacturing method described in Document 1. The exciting portion of the piezoelectric layer 14 is separated from the first support substrate 12, so that the SAW device having an improved excitation efficiency can be obtained.

According to the second method for manufacturing the acoustic wave device of the first embodiment, it is possible to easily manufacture the SAW device that has the piezoelectric layer 14 having uniform thickness and has the exciting portion of the piezoelectric layer 14 separated from the first support substrate 12. It is possible to easily manufacture the SAW device having excellent device characteristics such as K2 and TCV as illustrated in FIG. 5 with excellent productivity.

#### Second Embodiment

An acoustic wave device manufactured by a second embodiment is an exemplary FBAR. FIGS. 8A through 9D are cross-sectional views that illustrate a first method for manufacturing an acoustic wave device in accordance with the second embodiment. Referring to FIG. 8A, a metal film 40 is formed on the whole lower surface of the piezoelectric substrate 10 made of LT or LN by sputtering or evaporation technique. The metal film 40 may be made of Ru or Mo and may be 0.2  $\mu\text{m}$  to 0.5  $\mu\text{m}$  thick. Next, as illustrated in FIG. 8B, the unnecessary portions of the metal film 40 are removed by etching or the like, whereby second electrodes 42 are formed. The second electrode 42 is the lower electrode of the FBAR.

Referring to FIG. 8C, the lower surface of the piezoelectric substrate 10 on which the second electrodes 42 are formed is bonded to the upper surface of the first support substrate 12, which may be a silicon substrate. Referring to FIG. 8D, the piezoelectric substrate 10 is thinned to form the piezoelectric layer 14 in the state in which the piezoelectric substrate 10 has been bonded to the first support substrate 12.

Referring to FIG. 9A, the first electrodes 16 are formed on the upper surface of the piezoelectric layer 14 and located above the second electrodes 42 so as to overlap the second electrodes 42. The first electrodes 16 are the upper electrodes of FBARs. Referring to FIG. 9B, the first support substrate 12 is thinned to an extent that the second electrodes 42 are not exposed.

Referring to FIG. 9C, the holes 22 are formed by removing the portions of the first support substrate 12 located below the first electrodes 16 and the second electrodes 42. The areas in which the holes 22 are formed are larger than the areas in which the first electrodes 16 and the second electrodes 42 are formed. That is, the holes 22 are formed below the piezoelectric layer 14 in the areas in which the first electrodes 16 and the second electrodes 42 are formed.

Referring to FIG. 9D, the second support substrate 24, which may be a silicon substrate, for example, is bonded to the lower surface of the first support substrate 12. Thus, the holes 22 are formed into the hollow portions 26. A resonator is located above each hollow portion 26 and is composed of the piezoelectric layer 14, the second electrode 42 serving as the lower electrode on the lower surface of the piezoelectric layer 14, and the first electrode 16 serving as the upper electrode on the upper surface thereof. The piezoelectric layer 14

sandwiched the second electrode 42 and the first electrode 16 is an exciting portion, which is separated from the first support substrate 12.

As described above, according to the first method for manufacturing the acoustic wave device of the second embodiment, as illustrated in FIGS. 8A and 8B, the second electrodes 42 are formed to the lower surface of the piezoelectric substrate 10. Next, as illustrated in FIG. 8C, the lower surface of the piezoelectric substrate 10 on which the second electrodes 42 are formed is bonded to the upper surface of the first support substrate 12. Then, as illustrated in FIG. 8D, the piezoelectric substrate 10 is thinned to form the piezoelectric layer 14. After that, as illustrated in FIG. 9A, the first electrodes 16 are formed on the upper surface of the piezoelectric layer 14 located above the second electrodes 42. The first support substrate 12 is thinned as illustrated in FIG. 9B, and the holes 22 are formed in the areas of the first support substrate 12 located below the first electrodes 16 and the second electrodes 42. Finally, as illustrated in FIG. 9D, the second support substrate 24 is bonded to the lower surface of the first support substrate 12.

According to the first method for manufacturing the acoustic wave device of the second embodiment, it is possible to easily manufacture the FBAR that has the piezoelectric layer 14 having uniform thickness and has the exciting portion of the piezoelectric substrate 14 separated from the first support substrate 12 with excellent productivity.

When the piezoelectric layer 14 is made of LT, the acoustic wave device of the second embodiment has a capability of efficiently exciting a thickness-shear (TS) wave, and has excellent device characteristics such as K2 and TCV.

A description is now given, with reference to FIGS. 10A through 11D, of a second method for manufacturing an acoustic wave device in accordance with the second embodiment. Referring to FIG. 10A, the second electrodes 42, which are the lower electrodes of FBARs, are formed on the lower surface of the piezoelectric substrate 10. Referring to FIG. 10B, in parallel with the process of forming the second electrodes 42, the recess portions 36 are formed in the upper surface of the first support substrate 12 and are filled with the sacrificing layer 38. Referring to FIG. 10C, the upper surface of the first support substrate 12 in which the sacrificing layer 38 is formed and the lower surface of the piezoelectric substrate 10 on which the second electrodes 42 are formed are bonded together. This bonding is carried out so that the areas in which the sacrificing layer 38 is provided and the areas in which the second electrodes 42 are formed to overlap each other. Referring to FIG. 10D, the piezoelectric substrate 10 is thinned in the state in which the piezoelectric substrate 10 has been bonded to the first support substrate 12 to form the piezoelectric layer 14.

Referring to FIG. 11A, the first electrodes 16 are formed on the upper surface of the piezoelectric layer 14 in positions above the areas in which the sacrificing layer 38 is formed. That is, the first electrodes 16 and the second electrodes 42 are provided so as to overlap each other. Referring to FIG. 11B, the first support substrate 12 is thinned until the sacrificing layer 38 is exposed. Referring to FIG. 11C, the exposed sacrificing layer 38 is removed to form the holes 22 in the first support substrate 12 located below the first electrodes 16 and the second electrodes 42. Referring to FIG. 11D, the second support substrate 24 is bonded to the lower surface of the first support substrate 12.

The method for manufacturing the acoustic wave device in accordance with the second embodiment uses the sacrificing layer 38. However, as in the case of the second manufacturing method of the first embodiment, it is possible to easily manu-

facture the FBAR that has the piezoelectric layer 14 having uniform thickness and has the exciting portion of the piezoelectric substrate 14 separated from the first support substrate 12 with excellent productivity.

#### Third Embodiment

An acoustic wave device manufactured by a third embodiment is an SAW device in which a silicon oxide film is provided to the lower surface of the piezoelectric layer 14. FIGS. 12A through 12E are schematic cross-sectional views that illustrate a method for manufacturing the acoustic wave device in accordance with the third embodiment. Referring to FIG. 12A, a silicon oxide film 44 is deposited on the whole lower surface of the piezoelectric substrate 10 made of LT or LN. The thickness of the silicon oxide film 44 is 1  $\mu\text{m}$ , for example. Referring to FIG. 12B, the lower surface of the piezoelectric substrate 10 on which the silicon oxide film 44 is formed is bonded to the upper surface of the first support substrate 12, which may be a silicon substrate, for example.

Referring to FIG. 12C, the piezoelectric substrate 10 is thinned to form the piezoelectric layer 14 in the state in which the piezoelectric substrate 10 has been bonded to the first support substrate 12. Then, the first electrodes 16 are formed on the upper surface of the piezoelectric layer 14. Referring to FIG. 12D, the first support substrate 12 is thinned, and the portions of the first support substrate 12 below the first electrodes 16 are removed to form the holes 22. Referring to FIG. 12E, the second support substrate 24, which may be a silicon substrate, for example, is bonded to the lower surface of the first support substrate 12.

The acoustic wave device manufactured by the method in accordance with the third embodiment has the silicon oxide film 44 provided on the lower surface of the piezoelectric layer 14. In a case where the piezoelectric layer 14 is as thin as 1 $\times$ , for example, the silicon oxide film 44 attached to the lower surface of the piezoelectric layer 14 results in a temperature compensation effect. That is, the silicon oxide film 44 functions as a temperature compensation film. Since the silicon oxide film 44 is not provided on the first electrodes 16 but is provided to the lower surface of the piezoelectric layer 14, the silicon oxide film 44 does not have any roughness and leads to excellent propagation characteristics.

As described above, according to the manufacturing method of the third embodiment, the silicon oxide film 44 is formed to the lower surface of the piezoelectric substrate 10 as illustrated in FIG. 12A, and the lower surface of the piezoelectric substrate 10 on which the silicon oxide film 44 is formed is bonded to the upper surface of the first support substrate 12 as illustrated in FIG. 12B. Then, as illustrated in FIG. 12C, the piezoelectric substrate 10 is thinned to form the piezoelectric layer 14, and the first electrodes 16 are formed on the upper surface of the piezoelectric layer 14. After that, as illustrated in FIG. 12D, the holes 22 are formed in the areas of the first support substrate 12 located below the first electrodes 16. As illustrated in FIG. 12E, the second support substrate 24 is bonded to the lower surface of the first support substrate 12. It is possible to easily manufacture the SAW device that has the piezoelectric layer 14 having uniform thickness, the exciting portion of the piezoelectric substrate 14 separated from the first support substrate 12, and the silicon oxide film 44 functioning as the temperature compensation layer with excellent productivity.

The insulative film provided on the lower surface of the piezoelectric layer 14 is not limited to the silicon oxide film 44 but may be another insulative film that functions as the temperature compensation layer.

The acoustic wave device of the third embodiment may be manufactured by a method using the sacrificing layer 38 like the second manufacturing method of the first embodiment described with reference to FIGS. 6A through 7D. In this case, the step of FIG. 12A is carried out to deposit the silicon oxide film 44 on the whole lower surface of the piezoelectric substrate 10. Then, the process described with reference to the FIGS. 6A through 7D is carried out.

#### Fourth Embodiment

An acoustic wave device manufactured by a fourth embodiment is an exemplary SAW device using the piezoelectric layer 14 composed of two piezoelectric layers having mutually opposite directions of polarization. FIGS. 13A through 14D are schematic cross-sectional views that illustrate a method for manufacturing the acoustic wave device in accordance with the fourth embodiment. Referring to FIG. 13A, a lower surface of a first piezoelectric substrate 46 is bonded to the upper surface of the first support substrate 12, which may be a silicon substrate, for example. The first piezoelectric substrate 46 may be an LT substrate or an LN substrate having an upward direction of polarization is, as indicated by an arrow in FIG. 13A. Referring to FIG. 13B, the first piezoelectric substrate 46 is thinned to form a first piezoelectric layer 48 having a thickness of  $10\lambda$ , for example.

Referring to FIG. 13C, a lower surface of a second piezoelectric substrate 50 is bonded to an upper surface of the first piezoelectric layer 48. The second piezoelectric substrate 50 is made of the same material as the first piezoelectric substrate 46, and has a downward direction of polarization, as indicated by an arrow in FIG. 13C. Referring to FIG. 13D, the second piezoelectric substrate 50 is thinned to form a second piezoelectric layer 52 having a thickness of  $0.2\lambda$ , for example.

Referring to FIG. 14A, the first electrode 16 is formed on the upper surface of the piezoelectric layer 14. Referring to FIG. 14B, the first support substrate 12 is thinned. Then, the first support substrate 12 in the areas below the first electrode 16 are removed to form the holes 22, as illustrated in FIG. 14C. Referring to FIG. 14D, the second support substrate 24, which may be a silicon substrate, is bonded to the lower surface of the first support substrate 12.

The inventors conducted a simulation in order to study that the use of the piezoelectric layer 14 composed of two piezoelectric layers having the mutually opposite directions of polarization brings about an improvement in the impedance characteristic. FIG. 15 is a schematic cross-sectional view of a structure used in the simulation in which the piezoelectric layer 14 is composed of the first piezoelectric layer 48 and the second piezoelectric layer 52 having the mutually opposite directions of polarization as indicated by arrows in FIG. 15. It is assumed that the first piezoelectric layer 48 is considerably thick with regard to the wavelength of the acoustic wave. The first piezoelectric layer 48 is formed by  $222^\circ$ -rotated Y-cut LT. The second piezoelectric layer 52 is formed by  $42^\circ$ -rotated Y-cut LT and is  $0.2\lambda$  thick. One pair 18 of comb-tooth electrodes that is made of aluminum and has the infinite period is formed on the upper surface of the piezoelectric substrate 14. The first piezoelectric layer 48 has a thickness equal to or larger than  $1\lambda$ .

FIG. 16 illustrates results of the simulation. The horizontal axis of FIG. 16 is the normalized frequency, and the vertical axis thereof is the impedance. Solid lines in FIG. 16 indicate impedance characteristics obtained at room temperature ( $25^\circ\text{C}$ .), and broken lines are impedance characteristics at a high temperature ( $125^\circ\text{C}$ .). For the purpose of comparison, FIG. 16 illustrates the simulation results obtained when the piezo-



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electric substrate **10** having the general thickness illustrated in FIG. **4A** is used. As illustrated in FIG. **16**, the structure using the piezoelectric substrate **10** (thin lines in FIG. **16**) has K2 of 10%, a TCV of  $-18.4 \text{ ppm/}^\circ \text{C}$ . at the resonance frequency, and a TCV of  $-29.6 \text{ ppm/}^\circ \text{C}$ . at the anti-resonance frequency. The structure using the piezoelectric substrate **14** (thick lines in FIG. **16**) has an K2 of 3.6%, a TCV of  $+4.1 \text{ ppm/}^\circ \text{C}$ . at the resonance frequency, and a TCV of  $-9.5 \text{ ppm/}^\circ \text{C}$ . at the anti-resonance frequency.

As described above, the use the piezoelectric substrate **14** composed of the first piezoelectric layer **48** and the second piezoelectric layer **52** having the mutually opposite directions of polarization improves the device characteristics, more especially, TCVs at the resonance and anti-resonance frequencies.

According to the first method for manufacturing the acoustic wave device of the fourth embodiment, after the first piezoelectric substrate **46** is bonded to the upper surface of the first support substrate **12** as illustrated in FIG. **13A**, the first piezoelectric substrate **46** is thinned to form the first piezoelectric layer **48**, as illustrated in FIG. **13B**. Then, as illustrated in FIG. **13C**, the second piezoelectric substrate **50** that is made of the same material as the first piezoelectric layer **48** and has the polarization direction opposite to that of the first piezoelectric substrate **46** is bonded to the upper surface of the first piezoelectric substrate **46**. As illustrated in FIG. **13D**, the second piezoelectric substrate **50** is thinned to form the second piezoelectric layer **52**. Thus, the piezoelectric layer **14** composed of the first piezoelectric layer **48** and the second piezoelectric layer **52** is formed. Then, as illustrated in FIG. **14A**, the first electrode **16** is formed on the upper surface of the piezoelectric layer **14**. Thereafter, as illustrated in FIG. **14C**, the holes **22** are formed in the areas of the first support substrate **12** located below the first electrode **16**. Then, as illustrated in FIG. **14D**, the second support substrate **24** is bonded to the lower surface of the first support substrate **12**. It is possible to easily manufacture the SAW device that has the piezoelectric layer **14** configured to be composed of the first piezoelectric layer **48** and the second piezoelectric layer **52** and have uniform thickness and that has the exciting portion of the piezoelectric substrate **14** separated from the first support substrate **12** with excellent productivity. That is, as illustrated in FIG. **16**, it is possible to easily manufacture the SAW device having excellent device characteristics such as TCV with excellent productivity.

The acoustic wave device of the fourth embodiment may be manufactured by using the sacrificing layer **38** like the second manufacturing method of the first embodiment described with reference to FIGS. **6A** through **7D**. In this case, as illustrated in FIG. **17A**, the first support substrate **12** having the recess portions **36** full of the sacrificing layer **38** is prepared, and the first piezoelectric substrate **46** is bonded to the upper surface of the first support substrate **12** in which the sacrificing layer **38** is formed. Then, as illustrated in FIG. **17B**, the first piezoelectric substrate **46** is thinned to form the first piezoelectric layer **48**.

Referring to FIG. **17C**, the second piezoelectric substrate **50** is bonded to the upper surface of the first piezoelectric layer **48**. Then, as illustrated in FIG. **17D**, the second piezoelectric substrate **50** is thinned to form the second piezoelectric layer **52**, whereby the piezoelectric layer **14** composed of the first piezoelectric layer **48** and the second piezoelectric layer **52** is formed. The following steps are similar to those of the second manufacturing method of the first embodiment illustrated in FIGS. **7A** through **7D**, whereby the acoustic wave device of the fourth embodiment can be obtained.

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The acoustic wave device manufactured by the fourth embodiment is not limited to the SAW device but may be a piezoelectric thin-film resonator. In this case, the second electrodes **42**, which should be the lower electrodes of the resonators, are formed to the lower surface of the first piezoelectric substrate **46**. The lower surface of the first piezoelectric substrate **46** on which the second electrodes **42** are formed is bonded to the upper surface of the first support substrate **12**. Thereafter, steps similar to those illustrated in FIGS. **13A** through **14D** are carried out.

The first piezoelectric layer **48** and the second piezoelectric layer **52** may have different thicknesses. However, it is preferable that the first piezoelectric layer **48** and the second piezoelectric layer **52** have the same thickness as each other. This is because the same thickness excites the second harmonic, which is advantageous to manufacturing resonators operable at high frequencies.

The polarization directions of the first piezoelectric layer **48** and the second piezoelectric layer **52** are not limited to the aforementioned directions. The first piezoelectric layer **48** may have the downward direction of polarization, and the second piezoelectric layer **52** may have the upward direction of polarization.

Now, a second method for manufacturing an acoustic wave device in accordance with the fourth embodiment is described. First, like the first method described with FIGS. **13A** and **13B**, the first piezoelectric substrate **46** is bonded to the upper surface of the first support substrate **12**, and is thinned to form the first piezoelectric layer **48**. Next, the second piezoelectric layer **52** is formed on the upper surface of the first piezoelectric layer **48** by chemical vapor deposition (CVD), for example. The second piezoelectric layer **52** is made of the same material as the first piezoelectric layer **48** and has a polarization direction opposite to that of the first piezoelectric layer **48**. Thus, the piezoelectric layer **14** composed of the first piezoelectric layer **48** and the second piezoelectric layer **52** is formed as illustrated in FIG. **13D**. Then, steps similar to those of FIGS. **14A** through **14D** are carried out, whereby the acoustic wave device can be formed by the fourth embodiment.

According to the second method of the fourth embodiment, it is possible to easily manufacture the SAW device that has the piezoelectric layer **14** configured to be composed of the first piezoelectric layer **48** and the second piezoelectric layer **52** and have uniform thickness and that has the exciting portion of the piezoelectric substrate **14** separated from the first support substrate **12** with excellent productivity. That is, as illustrated in FIG. **16**, it is possible to easily manufacture the SAW device having excellent device characteristics such as TCV with excellent productivity.

The present invention is not limited to the specifically described embodiments, but other embodiments and variations thereof may be made without departing from the scope of the claimed invention.

What is claimed is:

1. A method for manufacturing an acoustic wave device comprising:

bonding a piezoelectric substrate to a first surface of a first support substrate;

thinning a whole of the piezoelectric substrate in a thickness direction of the piezoelectric substrate after the bonding to thus form a piezoelectric layer;

forming a first electrode on a first surface of the piezoelectric layer after the thinning of the piezoelectric substrate, the first surface of the piezoelectric layer being an opposite surface to a second surface of the piezoelectric layer located at a side of the first support substrate;

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forming holes in the first support substrate located below the first electrode; and  
bonding a second support substrate to a second surface of the first support substrate opposite to the first surface of the first support substrate after the forming of holes.

2. The method according to claim 1, further comprising thinning the first support substrate after the forming of the first electrode, wherein the forming of holes includes removing portions of the first support substrate that has been thinned from the second surface of the piezoelectric substrate opposite to the first surface of the piezoelectric substrate.

3. The method according to claim 1, further comprising forming recess portions in the first surface of the first support substrate before the bonding of the piezoelectric substrate, and burying a sacrificing layer in the recess portions, wherein: the bonding of the piezoelectric substrate includes bonding the piezoelectric substrate to the first surface of the first support substrate in which the sacrificing layer is formed;

the forming of the first electrode includes forming the first electrode above the sacrificing layer;

the method includes thinning the first support substrate from the second surface of the first support substrate after the forming of the first electrode until the sacrificing layer is exposed; and

the forming of holes includes removing the sacrificing layer that has been exposed from the second surface side of the first support substrate.

4. The method according to claim 1, further comprising forming an insulative film on a surface of the piezoelectric substrate that is to be bonded to the first surface of the first support substrate, wherein the bonding of the piezoelectric substrate includes bonding the surface of the piezoelectric substrate on which the insulative film is formed to the first surface of the first support substrate.

5. The method according to claim 1, further comprising forming a second electrode on a surface of the piezoelectric substrate before the bonding of the piezoelectric substrate, wherein:

the bonding of the piezoelectric substrate includes bonding the surface of the piezoelectric substrate on which the second electrode is formed to the first surface of the first support substrate; and

the forming of the first electrode includes forming the first electrode so as to be located above the second electrode.

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6. The method according to claim 5, wherein the acoustic wave device has the piezoelectric layer sandwiched between the first electrode and the second electrode.

7. The method according to claim 1, wherein the bonding of the piezoelectric substrate includes bonding a first piezoelectric substrate on the first surface of the first support substrate, and bonding a second piezoelectric substrate on a surface of a first piezoelectric layer obtained by thinning the first piezoelectric substrate after the bonding of the first piezoelectric substrate, the second piezoelectric substrate being made of a material identical to that of the first piezoelectric substrate and has a direction of polarization opposite to that of the first piezoelectric substrate,

wherein the forming of the piezoelectric layer includes thinning the second piezoelectric substrate to thus form a second piezoelectric layer, the piezoelectric layer being thus composed of the first piezoelectric layer and the second piezoelectric layer.

8. The method according to claim 1, wherein:

the bonding of the piezoelectric substrate includes bonding a first piezoelectric substrate to the first surface of the first support substrate;

the forming of the piezoelectric layer includes thinning the first piezoelectric substrate to form a first piezoelectric layer after the first piezoelectric substrate is bonded, and forming a second piezoelectric layer on the first piezoelectric layer;

the second piezoelectric layer is made of a material identical to that of the first piezoelectric layer and has a direction of polarization opposite to that of the first piezoelectric layer; and

the piezoelectric layer is composed of the first piezoelectric layer and the second piezoelectric layer.

9. The method according to claim 1, wherein the first electrode includes comb-tooth electrodes.

10. The method according to claim 1, wherein the piezoelectric layer is made of one of  $\text{LiTaO}_3$  and  $\text{LiNbO}_3$ .

11. The method according to claim 1, wherein the first and second support substrates are silicon substrates or substrates including silicon as a main component.

12. The method according to claim 1, wherein the thinning of the piezoelectric substrate includes thinning the piezoelectric substrate by grinding or polishing.

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